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EARTH SYSTEM SCIENCE LABORATORY
UNIVERSITY OF ALABAMA IN HUNTSVILLE
HUNTSVILLE, ALABAMA 35899

David Bowdle
Laurie Collins
Douglas Mach
Richard McNider
Aaron Song

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The University Of Alabama In Huntsville
Atmospheric Science and
Remote Sensing Laboratory
Kenneth E. Johnson Research Center
Huntsville, Alabama 35899
Phone: (205) 895-6257
FAX: (205) 895-6970

TO:	R. T. McNider, Director, Earth System Science Laboratory
FROM:	D. A. Bowdle, Doppler Lidar Principal Investigator
SUBJECT:	Final Report on Doppler Lidar Research
CONTRACT NUMBER:	NAS8-37585
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Attached is the Final Report on the contribution of the Earth Systems Science Laboratory, University of Alabama in Huntsville, to the Doppler Lidar research program of the Earth System Observing Branch, NASA Marshall Space Flight Center, under NASA Contract NAS8-37585.

FINAL REPORT ON DOPPLER LIDAR RESEARCH
CONTRACT NAS8-37585
April 1, 1989 -- September 30, 1992

DEVELOPMENT OF A GLOBAL BACKSCATTER MODEL FOR NASA'S LASER ATMOSPHERIC WIND SOUNDER

I. RESEARCH OVERVIEW

A. Summary

During the Contract Period April 1, 1989, to September 30, 1992, the Earth Systems Science Laboratory (ESSL) in the Research Institute at the University of Alabama in Huntsville (UAH) conducted a program of basic research on atmospheric backscatter characteristics, leading to the development of a global backscatter model. The ESSL research effort was carried out in conjunction with the Earth System Observing Branch (ES43) at the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center, as part of NASA Contract NAS8-37585 under the Atmospheric Dynamics Program at NASA Headquarters. This research provided important inputs to NASA's GLObal Backscatter Experiment (GLOBE) program, especially in the understanding of global aerosol life cycles, and to NASA's Doppler Lidar research program, especially the development program for their prospective space-based Laser Atmospheric Wind Sounder (LAWS).

B. Personnel

Listed below are the names, positions, and tenures of the ESSL personnel who were involved in this research effort.

<u>Scientists</u>

David A. Bowdle	Research Scientist	April 1989	-- September 1992
Maurice A. Jarzembski	Scientist	April 1989	-- December 1989
Dean R. Cutten	Research Scientist	June 1990	-- September 1992

<u>Database Managers</u>

Steven F. Williams	Research Associate	April 1989	-- March 1991
Michael Moore	Student Assistant	July 1990	-- March 1991
Helen Conover	Research Associate	March 1991	-- September 1991

<u>Staff Assistants (Meetings Coordination, Publications, Administrative)</u>

Dixie Upton		April 1989	-- June 1989
Laurie S. Collins		July 1989	-- September 1992
Reena Pearson		November 1990	-- December 1990
Cindy Taylor		April 1990	-- September 1992

C. Objective and Scope

The primary objective of this research is to develop a model of the volume backscatter coefficient (β, m^{-1} sr^{-1}) for trace atmospheric particulate matter over a wide range of spatial, temporal, and spectral scales. The model deals primarily with atmospheric aerosols and clouds, with lesser attention to gaseous molecular backscatter. It covers the troposphere and lower stratosphere, with special emphasis on low β values for so-called *background* aerosol populations in the middle and upper troposphere. Model-related studies deal with particulate distributions from the turbulent sub-microscale (~1 mm to ~10 m) to the global scale (>10,000 km), although actual model products span a much more limited range from the synoptic scale (~1000 km) to the global scale. Similarly, model inputs cover time periods from the sub-microscale (~1 µs) to the climatic (1-10 yr), while model outputs cover the synoptic (~1-10 da) to the climatic temporal scales. Research was conducted on aerosol backscatter, extinction, and related optical properties from ~0.3-15 µm wavelength, but again model products concentrated on β values at selected laser wavelengths in the near and middle infrared.

Development of this model required extensive compilation, careful review, and creative synthesis of aerosol data from a wide variety of sensors and sensor platforms. The deliverable products from this research include the backscatter model data inputs, the backscatter model data products, the analytical methods used to synthesize the model products from the model inputs, and the scientific rationale used to design the analytical methods.

The ESSL model development effort is an integral part of NASA's GLOBE program. GLOBE focused on two major airborne field programs, the Fall 1989 (GLOBE I) and Spring 1990 (GLOBE II) backscatter survey missions over the Pacific Ocean on a DC-8 aircraft from NASA's Ames Research Center (ARC). These missions included two pulsed lidars, to probe aerosol backscatter above and below the aircraft; two continuous-wave (CW) focused Doppler lidars, to characterize backscatter at flight altitude; and several auxiliary sensors, to measure other physical, chemical, and optical properties of the aerosols at flight level. The instrument complement and the theater of operations were chosen to improve NASA's understanding of the physicochemical properties and the spatial/temporal distribution of tropospheric aerosols over the remote oceans.

D. Applications

Backscatter data products from the ESSL model are making important contributions to several facets of the LAWS program. In particular, the LAWS project uses ESSL backscatter predictions to obtain parametric estimates of LAWS performance for programmatic and engineering trade studies on LAWS. ESSL backscatter model products are also used in detailed Observing System Simulation Experiments (OSSE's) for LAWS, in order to assess the scientific impact of the decisions from these trade studies.

The results of this research are applicable to similar design studies and performance simulations for any earth-based or space-based lidar system that uses atmospheric aerosols as passive scattering targets for the measurement of winds or other primary atmospheric variables. This research is also providing important insights about the physical, chemical, and optical properties, the spatial/temporal structure, and the overall dynamics of the regional- to global-scale aerosol system.

II. RESEARCH DESCRIPTION

A. Tasks

ESSL participation in the GLOBE research program covered six general areas.

1. GLOBE/LAWS Program Leadership ESSL provided expert scientific leadership for NASA's GLOBE program and expert scientific representation to NASA's LAWS development program. Under this task, ESSL continually provided NASA MSFC and NASA Headquarters with state-of-the-art scientific information on atmospheric aerosol systems; their physical, chemical, and optical properties; their spatial and temporal distribution; and their probable effects on LAWS performance. This information was used in conjunction with NASA MSFC and NASA Headquarters to develop a scientifically sound rationale for the overall GLOBE research effort and the various elements of GLOBE; to develop realistic research programs based on that rationale; and to evaluate or modify those programs based on the evolving needs of the LAWS program. ESSL supplemented these efforts by coordinating, administering, and documenting periodic meetings of the GLOBE and LAWS Science Teams.

2. GLOBE Science Team Coordination ESSL coordinated the research efforts of the GLOBE Science Team. This activity included designing and directing major GLOBE field programs; directing GLOBE data processing and data analysis; coordinating GLOBE special sessions at open scientific conferences; and serving as Lead Guest Editor for a special GLOBE section of a prominent earth science research journal.

3. GLOBE Database Development ESSL designed, developed, implemented, and maintained a centralized, remotely accessible, interactive GLOBE database at MSFC. This effort covered the hardware, data archival software, and data visualization software, as well as data compilation, cataloging, archival, and distribution.

4. GLOBE Model Development ESSL used the comprehensive GLOBE database to develop an empirical global-scale model of aerosol backscatter for input to the LAWS development effort. This activity involved developing customized data visualization software modules; reviewing and quality controlling GLOBE data; intercomparing contemporaneous GLOBE data sets; characterizing the physical, chemical, and optical properties of atmospheric aerosols from the GLOBE data; and synthesizing the combined results of the GLOBE program into a global-scale aerosol backscatter model.

5. Aerosol Laboratory Development ESSL developed a new aerosol analysis laboratory at MSFC. This activity included designing and implementing the laboratory layout, installing MSFC lidars in the laboratory, equipping the laboratory with aerosol analysis accessories, using the lidars to measure aerosol optical properties, and developing computer codes that simulate the lidar measurement process.

6. Publications, Presentations, Reviews ESSL presented numerous papers on GLOBE results, published several GLOBE papers, and reviewed a variety of proposals and journal manuscripts.

B. Key Results

1. GLOBE/LAWS PROGRAM LEADERSHIP

a. GLOBE Program Design D. Bowdle developed the scientific rationale for the entire GLOBE research program, and particularly for the GLOBE survey missions. This rationale was based on the premise that GLOBE should concentrate on aerosol targets near the detection

threshold for the current or prospective LAWS design. Using this premise, GLOBE studies for the initial LAWS instrument were designed to provide information on aerosol backscatter properties at 9.1 μm in the middle and upper troposphere, especially over the remote oceans. During late 1991 and all of 1992, the focus of the LAWS program shifted toward smaller, less complex, less risky, and less costly versions of LAWS, possibly at a shorter wavelength, such as 2.1 μm. Using the same premise, GLOBE studies for LAWS began to emphasize higher backscatter targets, such as thin clouds, continental aerosol plumes, convective boundary layer plumes, and the continental and marine boundary layers, at a variety of wavelengths. This change in emphasis could have a profound effect on the design of future GLOBE measurement programs. During this same time, D. Bowdle and D. Cutten made major contributions to a new MSFC proposal for continuing GLOBE aerosol research by the ES43 Aerosol/Lidar Group.

b. GLOBE Science Team Meetings The GLOBE Science Working Group (SWG) met in May 1989, to evaluate readiness for the Fall 1989 GLOBE Survey mission, and in March 1990, to review the results of the Fall Survey mission and evaluate readiness for the Spring 1990 Survey mission. The SWG met again in May 1991 and April 1992 to review mature results from the combined missions. The 1991 meeting featured high-end desktop computers for on-site intercomparisons of the measurements from various GLOBE instruments. ESSL organized the technical sessions and handled the logistical arrangements for all of these meetings, then published the proceedings for most of the meetings. One or more ESSL scientists attended these meetings and presented the results of their GLOBE research, emphasizing the typical values and the spatial and temporal variability of atmospheric aerosol backscatter.

c. LAWS Science Team Participation The LAWS Science Team met twice each in 1989, 1990, 1991, and 1992. ESSL hosted and arranged most of these meetings and published Proceedings for all of the meetings. One or more ESSL scientists attended each meeting.

D. Bowdle joined the Science Team as an Associate Member in early 1989, at the invitation of NASA and the LAWS Science Team Leader. Shortly thereafter, he became Chairman of the LAWS Backscatter Subcommittee. In these capacities, he provided long-term scientific liaison between the GLOBE research program and the LAWS development program. At each Science Team meeting, he presented GLOBE status, plans, and recent results, emphasizing implications for LAWS design and performance. He led LAWS Backscatter Committee meetings, to determine the current and projected needs of the LAWS program for GLOBE data inputs. He also presented Committee findings and recommendations to the Science Team, and documented those results for the Meeting Proceedings.

d. LAWS Design Review D. Bowdle attended numerous quarterly review meetings for the LAWS Phase I/II prime contractors. He also attended various presentations on alternate LAWS design concepts by other contractors, and prepared written technical reviews for NASA on some of these presentations. He also participated extensively in the effort to develop suitable scientific and engineering design concepts for a descoped version of LAWS. In this capacity, he provided information about aerosol backscatter properties and other atmospheric optical parameters for a wide variety of laser wavelengths and atmospheric conditions. He also prepared a preliminary model of the wavelength dependence and frequency of occurrence for backscatter coefficients and LAWS signal-to-noise ratios at several LAWS power levels and the two prime laser wavelengths, 9.1 μm and 2.1 μm in the dominant tropospheric aerosol types. He presented these results, along with an overview of the GLOBE results, to Dr. Shelby Tilford, Director of the Earth Science and Applications Division at NASA Headquarters. He also attended the 2 μm

Solid State Laser Technology Assessment for Remote Sensing of Winds, again at NASA Headquarters.

2. GLOBE SCIENCE TEAM COORDINATION

a. Field Programs ESSL designed, coordinated, and participated heavily in the GLOBE I and GLOBE II airborne backscatter survey missions over the Pacific Ocean. The GLOBE I deployment was delayed and re-routed due to instrument problems. Once deployment began, most instruments performed well and flight operations were conducted essentially as planned under the modified routing. The mission included both long-distance, high-altitude transit flights around the Pacific basin, and detailed local flights at selected sites for comparison with independent aerosol research stations. A wide variety of meteorological conditions was encountered during the deployment, with corresponding changes evident in aerosol properties. After major improvements in all instruments, the Spring survey mission deployed on schedule. The general routing, the individual flight plans, and the meteorological variety for this mission were similar to those in the Fall mission, except for a seasonal reversal in hemispheric aerosol properties. All instruments performed very well.

D. Bowdle served as Mission Science Coordinator for both survey missions. Before deployment, he developed the scientific framework for each mission; designed flight plan concepts to meet key scientific objectives; defined requirements for supporting measurements; and assisted in preparing the Mission operations plan documents. During deployment, he collected weather forecast data; participated in preflight planning; provided in-flight meteorological observations; directed in-flight sample collection and documentation; contributed to in-flight maneuver planning; coordinated near-real-time and post-flight data review; and maintained liaison between the Mission Scientist and the Principal Investigators. After deployment, he coordinated data processing, analysis, and validation efforts, and organized overall mission debriefings.

S. Williams served as Mission Logistics Coordinator and Mission Data Base Manager. Before deployment, he developed detailed plans for implementing flight plan concepts; represented MSFC on a scientific, logistical, and political site survey tour; traveled frequently to NASA ARC and NASA Headquarters for mission planning discussions; monitored interagency and international arrangements; arranged for supporting meteorological and aerosol measurements from numerous ground-based, airborne, and satellite stations; and prepared Mission Operations Plan Documents. During deployment, he stayed in Huntsville; confirmed logistics and science support arrangements; and maintained communications links with the Mission Science Team. After deployment, he developed data transmission arrangements with the PI's and began compiling and archiving Survey data.

M. Jarzembski served as a Lidar Scientist for MSFC's CW CO_2 Doppler lidars. Before deployment, he participated in detailed lidar calibration at MSFC and assisted in lidar integration, checkout, and calibration at ARC. During deployment, he participated in routine lidar operations and data collection. After deployment, he assisted in lidar demounting and calibration at ARC, and in detailed lidar calibration at MSFC. Several months after the GLOBE II mission, he became a NASA MSFC employee, where he continued his work with the MSFC lidars.

D. Cutten served as Aerosol Scientist for two intercomparison flights between the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) F-27 aerosol research aircraft and the NASA DC-8 GLOBE aircraft. These flights were conducted near

Tasmania during GLOBE I. After GLOBE II, he traveled to the United States, joined ESSL, and began analyzing the CSIRO and DC-8 intercomparison data. Subsequently, he became System Manager and Data Quality Manager for the GLOBE database.

b. GLOBE Science Coordination D. Bowdle coordinated GLOBE SWG efforts in processing and analyzing data from the GLOBE Survey Missions and related GLOBE measurement programs. Goals and priorities for this effort were determined from NASA's evolving needs and from the scientific framework developed by ESSL for the GLOBE program. Some aspects of this coordination were implemented by routine telephone or mail contact with GLOBE investigators, some by annual GLOBE SWG meetings, and some by closer personal interaction, as noted below.

In summer 1989, D. Bowdle and other scientists in the MSFC Aerosol/Lidar group, worked closely with Mr. John Porter, Ph.D. candidate at the University of Hawaii (UH), during his summer internship at MSFC. Mr. Porter analyzed the relationships between the size distributions and the visible and infrared optical properties of marine free tropospheric aerosols. The data used in this study were obtained by UH researcher Dr. Antony Clarke, during the Fall 1988 Mauna Loa Aerosol Backscatter Intercomparison Experiment (MABIE) on the Big Island of Hawaii.

In November 1991, D. Bowdle visited the home institutions for most of the GLOBE Principal Investigators. The purpose of these site visits was to evaluate GLOBE data processing procedures and data quality; to assess selected scientific implications of GLOBE data; to expedite release of GLOBE data to the GLOBE database at MSFC; and to provide timely inputs of validated GLOBE data to the LAWS development program.

c. GLOBE Special Sessions D. Bowdle organized special GLOBE sessions in three scientific conferences:

- *Fifth Conference, Coherent Laser Radar Technology and Applications, Munich, Germany, June 5-9, 1989;*
- *Fall Meeting, American Geophysical Union, December 3-7, 1990, San Francisco, California;*
- *Annual Meeting, American Meteorological Society, Seventh Symposium, Meteorological Observations and Instrumentation, Special Session on Laser Atmospheric Studies, New Orleans, Louisiana, January 14-18, 1991.*

Mr. Bowdle also served as Session Chairman for the Backscatter Session at Munich.

d. GLOBE Special Issue From September 1987 until March 1991, D. Bowdle served as Guest Editor for a special GLOBE section of fifteen papers in the *Journal of Geophysical Research - Atmospheres* (*JGR*). This effort included soliciting papers, coordinating external reviews, performing editorial reviews, and coordinating with *JGR*. Most editorial responsibilities were performed during 1989. The special section was published in March 1991.

3. GLOBE DATABASE DEVELOPMENT

a. Hardware Architecture D. Cutten designed and implemented a centralized, remotely accessible, interactive workstation architecture for the GLOBE database at NASA MSFC. The design centers on a Silicon Graphics 4D25 UNIX workstation (CIRRUS) with magneto-optical disk mass storage, ETHERNET connectivity to MSFC GLOBE researchers and other MSFC computing resources, and INTERNET connectivity to external GLOBE researchers. Considerable effort was expended in installing, maintaining, and upgrading this vital resource.

b. Data Archival Software Architecture D. Cutten designed and implemented user-friendly archival software for the database. Customized software modules read each type of GLOBE data, convert it to Hierarchical Data Format (HDF), install standardized file headers, and

assign standardized filenames. Each module is built on the standard HDF template. HDF, from the National Center for Supercomputing Applications, provides several versatile features that enhance routine data access for interactive management, retrieval, visualization, and analysis of the GLOBE data. In particular, HDF is one of the standard built-in formats for data importation into several key data visualization software packages (see next item). Use of HDF also maintains compatibility with NASA's Earth Observing System Data and Information System (EOSDIS).

c. Data Visualization Software Architecture D. Cutten evaluated and implemented several powerful object-oriented interactive data visualization software packages for CIRRUS. Most data visualization work to date was conducted using the LINKWINDS code from NASA's Jet Propulsion Laboratory. Dr. Cutten served as a BETA Tester for LINKWINDS, where he was instrumental in prompting numerous strategic improvements in the code.

d. Data Compilation, Archival, and Distribution Standard data management procedures were developed for the GLOBE database. Under these procedures, incoming GLOBE data sets were compiled, cataloged, copied onto backup media, and converted to HDF. By the end of the contract period, the database had received very little GLOBE I data, but almost all of the GLOBE II data except for ancillary meteorological data. Mass data archival of the GLOBE II data was in progress. Numerous requests for GLOBE data were received and fulfilled.

4. GLOBE MODEL DEVELOPMENT

a. Preprocessor Software D. Cutten, in conjunction with other ES43 Aerosol/Lidar Group members, developed several custom pre-processor codes to prepare various types of GLOBE data for false-color visualization on CIRRUS. These codes were used to display time *vs.* height cross-sections of aerosol backscatter coefficients from the GLOBE pulsed lidars, and time *vs.* particle size cross-sections of aerosol concentrations from the GLOBE optical particle counters. These displays were complemented by line plots of related aerosol and meteorological parameters at flight altitude.

b. Quality Control D. Cutten used the customized data visualization modules to conduct detailed studies of GLOBE data quality. These tools revealed several critical, but previously undocumented, limitations in the various data sets. These problems were documented and corrected where possible, in conjunction with the GLOBE PI's.

c. Sensor Intercomparison D. Cutten also used the data visualization tools to compare contemporaneous data sets from similar GLOBE sensors. These intercomparisons augmented the quality control process. Equally importantly, they provided empirical conversion factors from commonly measured aerosol parameters to the less commonly measured aerosol backscatter coefficients at LAWS design wavelengths.

d. Aerosol Physicochemical Modeling D. Cutten used measured and analytical aerosol size distributions as inputs to Mie scattering codes in computations of aerosol backscatter coefficients at 9.1 μm for several common aerosol constituents. The results showed that backscatter for mixed particles changes markedly with particle size, type of mixing (internal or external), and morphology of mixing (multiple phases with coated cores, or single phases with homogenous mixtures). Dr. Cutten also modeled aerosol backscatter dependence on particle size and wavelength for pure ice and water particles. The results of this study were used to interpret the empirical conversion factors discussed in item #c above.

e. Model Synthesis D. Bowdle synthesized results from the GLOBE survey missions, other GLOBE measurement programs, and related aerosol data sets, into a model of aerosol

backscatter properties in the major tropospheric aerosol regimes. This preliminary empirical model describes the frequency of occurrence of each aerosol type, and the corresponding frequency of occurrence for any given aerosol backscatter value at the 9.1 μm and 2.1 μm laser wavelengths. It also describes the atmospheric processes that regulate the regional- and global-scale transfer of air mass and aerosol mass from one aerosol domain to another. These model studies have confirmed the existence of a remarkably uniform and stable global-scale aerosol background population in the middle and upper troposphere. (*Rothermel et al.*, 1989).

5. AEROSOL LABORATORY DEVELOPMENT

a. Operation M. Jarzembski, D. Bowdle, and allied MSFC researchers designed and implemented an Aerosol Optical Properties Laboratory (AOPL) at MSFC. The AOPL is equipped to obtain calibrated measurements of backscatter coefficients from a variety of artificial aerosols, using MSFC's 9.11-μm and 10.6-μm CW CO_2 focused Doppler lidars. AOPL research objectives include: evaluation of lidar performance theory; development of improved lidar backscatter calibration methods; measurement of wavelength-dependent aerosol backscatter; and eventual establishment of transfer functions between CO_2 backscatter and aerosol optical properties at other wavelengths. M. Jarzembski (an MSFC employee since late 1989) operates the AOPL; D. Bowdle provides general scientific oversight.

b. Measurements M. Jarzembski used the AOPL extensively to calibrate the MSFC CW lidars before and after lidar deployment on the GLOBE Survey Missions. Subsequently, he conducted exploratory experiments with a new discrete particle calibration methodology, and found excellent agreement with analytical theory for lidar performance in this measurement mode. He also compared the performance of the CW lidars using both traditional "hard" target (e.g., sandpaper) calibration methodology and the new discrete-particle methodology.

c. Lidar Measurement Theory D. Bowdle developed a microcomputer-based Monte-Carlo simulation code for the CW lidars to explain the details of signal distributions observed during the discrete-particle calibration experiments. To complement this code, he also developed a simple parameterization for backscatter cross-section distributions in typical populations of artificial and natural aerosols.

6. PUBLICATIONS, PRESENTATIONS, REVIEWS

a. Publications ESSL researchers published several papers in the open scientific literature. D. Bowdle authored two papers and co-authored six papers; five of these papers were included in the GLOBE Special Section of *JGR*. In addition, M. Jarzembski authored one paper and co-authored two (one after leaving ESSL), while D. Cutten co-authored one paper. Nine of the eleven papers were either directly or peripherally related to GLOBE. These papers are itemized in Section III.

b. Presentations ESSL researchers presented several papers in open scientific conferences. D. Bowdle presented nine papers and co-authored four papers in eight conferences. S. Williams co-authored three papers in three conferences, and D. Cutten co-authored one paper in one conference. All fourteen papers were either directly or peripherally related to GLOBE. These presentations are itemized in Section III.

c. Reviews D. Bowdle reviewed one paper for *Applied Optics*, two papers for the *Bulletin of the American Meteorological Society*, three proposals for the proposal authors, and three proposals for NASA Headquarters. These reviews were in addition to the Guest Editor reviews for the GLOBE Section of *JGR*.

PUBLICATIONS - JOURNAL ARTICLES

Rothermel, J., **D. A. Bowdle**, J. M. Vaughan, and M. J. Post, 1989: "Evidence of a tropospheric aerosol background backscatter mode." *Appl. Opt.*, **28**, 1040-1042.

Vaughan, J. M., **D. A. Bowdle**, R. Callan, and J. Rothermel, 1989: "Spectral analysis, digital integration, and measurement of low backscatter in coherent laser radar." *Appl. Opt.*, **28**, 3008-3014.

Jarzembski, M. A., and V. Srivastava, 1989: "The electromagnetic field enhancement in small liquid droplets using geometrical optics." *Appl. Opt.*, **28**, 4962-4965.

Chýlek, P., **M. A. Jarzembski**, V. Srivastava, and R. G. Pinnick, 1990: "Pressure dependence of the laser-induced breakdown threshold of gases and droplets." *Appl. Opt.*, **29**, 2303-2306.

Bowdle, D. A., J. Rothermel, J. M. Vaughan, D. W. Brown, and M. J. Post, 1991: "Aerosol backscatter measurements at 10.6 micrometers with airborne and ground-based CO_2 Doppler lidars over the Colorado High Plains, 1, lidar intercomparison." *J. Geophys. Res.*, **96**, 5327-5335.

Bowdle, D. A., J. Rothermel, J. M. Vaughan, and M. J. Post, 1991: "Aerosol backscatter measurements at 10.6 micrometers with airborne and ground-based CO_2 Doppler lidars over the Colorado High Plains, 2, Backscatter structure." *J. Geophys. Res.*, **96**, 5337-5344.

Patterson, E. M., and **D. A. Bowdle**, 1991: "Use of aerosol microphysical measurements to model IR backscatter in support of GLOBE." *J. Geophys. Res.*, **96**, 5315-5326.

Rothermel, J., **D. A. Bowdle**, J. M. Vaughan, D. W. Brown, and A. A. Woodfield, 1991: "Calculation of aerosol backscatter from airborne CW focused CO_2 Doppler lidar measurements, 1, algorithm description." *J. Geophys. Res.*, **96**, 5293-5298.

Rothermel, J., **D. A. Bowdle**, and J. M. Vaughan, 1991: "Calculation of aerosol backscatter from airborne CW focused CO_2 Doppler lidar measurements, 2, algorithm performance." *J. Geophys. Res.*, **96**, 5299-5305.

Srivastava, V., M. Jarzembski, and **D. Bowdle**, 1992: "Comparison of calculated aerosol backscatter at 9.1 μm and 2.1 μm wavelengths." *Appl. Opt.*, **31**, 1904-1906.

Young, S. A., **D. R. Cutten**, M. J. Lynch, and J. E. Davies, 1993: "Lidar-derived variations in the backscatter-to-extinction ratio in southern hemisphere coastal maritime aerosols." Accepted for publication in *Atmospheric Environment*.

PUBLICATIONS - REPORTS

Williams, S. F., and **D. A. Bowdle** (Eds.), 1989: *Preliminary Data Inventory for the Fall-1988 Mauna Loa Aerosol Backscatter Intercomparison Experiment (MABIE)*, University of Alabama in Huntsville, Huntsville, Alabama, March 1989.

Williams, S. F., and **D. A. Bowdle** (Eds.), 1989: *First GLObal Backscatter Experiment (GLOBE) Survey Mission Flight Plan Document*, University of Alabama in Huntsville, Huntsville, Alabama. 62 pp, October 1989.

Williams, S. F., and D. A. Bowdle (Eds.), 1990: *GLObal Backscatter Experiment (GLOBE), Second Survey Mission Flight Plan Document, May-June 1990*, University of Alabama in Huntsville, Huntsville, Alabama. 61 pp, April 1990.

Bowdle, D. A. (Ed.), 1991: *Proceedings, Ninth Meeting of the GLObal Backscatter Experiment (GLOBE) Scientific Working Group, Guntersville, Alabama, April 23-25, 1991.* University of Alabama in Huntsville, Huntsville, Alabama.

Bowdle, D. A. (Ed.), 1992: *Proceedings, Tenth Meeting of the GLObal Backscatter Experiment (GLOBE) Scientific Working Group, Mountain View, California, April 7-8, 1992.* University of Alabama in Huntsville, Huntsville, Alabama.

PUBLICATIONS - PRESENTATIONS

Conferences

Proceedings, *Fifth Conference on Coherent Laser Radar: Technology and Applications, Munich, Germany, June 5-9, 1989*, Deutsche Forschungsanstalt fur Luft- und Raumfahrt, Munich, Germany:

Bowdle, D. A., "The GLObal Backscatter Experiment." pp. 221-224.

Rothermel, J., **D. A. Bowdle**, R. T. Menzies, M. J. Post, and J. M. Vaughan, "Tropospheric Aerosol Backscatter Background Mode at CO_2 Wavelengths." pp 229-232.

European Association for the Science of Air Pollution (EURASAP), *International Conference on Aerosols and Background Pollution*, University College, Galway, Ireland, June 13-15, 1989:

Bowdle, D. A., "Development of a global-scale background aerosol model."

Bowdle, D. A., E. M. Patterson, M. J. Post, and A. D. Clarke, "The Mauna Loa Aerosol Backscatter Intercomparison Experiment (MABIE)."

Post, M. J., and **D. A. Bowdle**, "Observations of a possible Gobi dust event by infrared lidar near Mauna Loa, Hawaii."

Rothermel, J., **D. A. Bowdle**, R. T. Menzies, M. J. Post, and J. M. Vaughan, "Evidence of a tropospheric aerosol backscatter background mode at CO_2 wavelengths."

GLOBE Special Session, American Geophysical Union Fall Meeting, December 3-7, 1990, San Francisco, California:

Bowdle, D. A., J. Rothermel, and J. E. Arnold, "GLOBE research and results."

Preprints, *Seventh Symposium on Meteorological Observations and Instrumentation, Special Session on Laser Atmospheric Studies, Annual Meeting of the American Meteorological Society, New Orleans, Louisiana, January 14-18, 1991*, American Meteorological Society, Boston MA:

Bowdle, D. A., S. F. Williams, and J. Rothermel: "The GLObal Backscatter Experiment."

Srivastava, V., A. D. Clarke, J. Porter, and **D. A. Bowdle**: "Comparison of CO_2 backscatter using Mie theory from aerosol measurements over Pacific basin with lidar data." pp. J268-J271.

Young, S. A., D. R. Cutten, M. J. Lynch, and J. E. Davies: "Lidar-derived backscatter and extinction of maritime aerosols." pp. J219-J222.

Proceedings, *Fourth Airborne Geoscience Workshop, January 29-February 1, 1991, LaJolla, California,* National Aeronautics and Space Administration, Washington, D.C.:

Bowdle, D. A., J. Rothermel, J. E. Arnold, and S. F. Williams: "GLObal Backscatter Experiment Pacific Survey Mission." pp. 107-110.

Coherent Laser Radar: Technology and Applications; Snowmass, Colorado, July 8-12, 1991, Technical Digest Series, Vol. 12, Optical Society of America, Washington, D. C.:

Bowdle, D. A., J. Rothermel, J. E. Arnold, and S. F. Williams, "The GLObal Backscatter Experiment Pacific Survey Mission: Results and implications for LAWS." pp 290-292.

International Symposium on Active Sensors and Non-Synchronous Missions Dedicated to GEWEX, Jouy en Josas, France, June 15-19, 1992:

Bowdle, D. A., J. Rothermel, and J. E. Arnold, "GLObal Backscatter Experiment airborne Pacific Survey Mission: Major findings and prospects."

Sixteenth International Laser Radar Conference, Massachusetts Institute of Technology, Cambridge, Massachusetts, July 19-24, 1992, National Aeronautics and Space Administration Conference Publications, Pub. 3158, Part I, Washington, D. C.:

Bowdle, D. A., "GLObal Backscatter Experiment (GLOBE) results: Aerosol backscatter wavelength dependence and global distribution." pp 57-60.

NASA Headquarters Workshops, Etc.

Bowdle, D. A., "GLOBE data plan." Presented at NASA Headquarters Global-Scale Atmospheric Processes Research Review, NASA Marshall Space Flight Center, Huntsville, Alabama, July 12-13, 1990.

Bowdle, D. A., "GLOBE Pacific Survey Mission: Preliminary results." Presented at NASA Langley Research Center, Hampton, Virginia, during a visit by the MSFC LAWS Project Team, November 13, 1991.

Bowdle, D. A., "GLObal Backscatter Experiment." Presented to Dr. Shelby Tilford at NASA Headquarters, Washington, D.C., February 7, 1992.

Bowdle, D. A., "Aerosol backscatter wavelength dependence." Presented by invitation at the *2 μm Solid State Laser Technology Assessment for Remote Sensing of Wind, NASA Headquarters, Washington, D.C., May 18-19, 1992.*

GLOBE Science Working Group (SWG) Meetings

Seventh GLOBE SWG Meeting, Huntsville, Alabama, May 2-3, 1989:

Bowdle, D. A., E. M. Patterson, M. J. Post, and A. D. Clarke, "The Mauna Loa Aerosol Backscatter Intercomparison Experiment (MABIE)"

Eighth GLOBE SWG Meeting, Huntsville, Alabama, March 7-8, 1990:

Bowdle, D. A., "GLOBE Survey Mission overview"

Bowdle, D. A., "GLOBE international intercomparison experiments"

Bowdle, D. A., "GLOBE Survey data processing and analysis plan"

Williams, S. F., "GLOBE Survey central data base"

Ninth GLOBE SWG Meeting, Guntersville, Alabama, April 22-25, 1991:

Bowdle, D. A., "GLOBE Survey Mission data analysis plan"

Cutten, D. R., "Modeled and measured aerosol size distributions"

Tenth GLOBE SWG Meeting, Mountain View, California, April 7-8, 1992:

Bowdle, D. A., "GLOBE backscatter analysis and modeling"

Bowdle, D. A., "GLOBE Science Working Group position paper"

Bowdle, D. A., "GLOBE science and data management plan"

<u>LAWS Science Team Meetings</u>

Second LAWS Science Team Meeting, Huntsville, Alabama, August 7-9, 1989:

Bowdle, D. A., "GLOBE measurement and modeling status"

Third LAWS Science Team Meeting, Pasadena, California, January 13-17, 1990:

Bowdle, D. A., "GLOBE Survey Mission overview"

Fourth LAWS Science Team Meeting, Boulder, Colorado, July 31 - August 3, 1990:

Bowdle, D. A., "Preliminary GLOBE results"

Fifth LAWS Science Team Meeting, Clearwater, Florida, February 4-6, 1991:

Bowdle, D. A., "GLOBE results and implications for LAWS"

Sixth LAWS Science Team Meeting, Snowmass Village, Colorado, July 15-17, 1991:

Bowdle, D. A., "GLOBE data processing update"

Seventh LAWS Science Team Meeting, Huntsville, Alabama, January 28-30, 1992:

Bowdle, D. A., "GLOBE update"

Eighth LAWS Science Team Meeting, North Falmouth, Massachusetts, July 26-30, 1992:

Bowdle, D. A., "GLOBE results: Aerosol backscatter wavelength dependence and global distribution"

TRAVEL

David Bowdle, June 2-11, 1989: Munich, Germany. Presented GLOBE results and served as Backscatter Session Chairman at the Fifth Conference on Coherent Laser Radar: Technology and Applications.

David Bowdle, June 11-16, 1989: University College, Galway, Ireland. Presented GLOBE results at the International Conference on Aerosols and Background Pollution.

Steve Williams, June 10-14, 1989: NASA Ames Research Center, Mountain View, California. Reviewed plans for the First GLOBE Survey Misssion.

Steve Williams, July 11-29, 1989: Auckland, Wellington, and Christchurch, New Zealand; Melbourne, Canberra, and Sydney, Australia; Tokyo, Japan; Honolulu, Hawaii; and San Francisco, California. Conducted site evaluations for the First GLOBE Survey Mission.

Steve Williams, August 28-29, 1989: NASA Headquarters, Washington, D.C. Reviewed plans for the First GLOBE Survey Mission.

Steve Williams, September 9-10, 1989: Boulder, Colorado. Discussed data support activities for the First GLOBE Survey Mission with NOAA scientists.

Maurice Jarzembski, September 14-22, 1989: NASA Ames Research Center, Mountain View, California. Conducted preflight calibrations on the MSFC CW CO_2 Doppler lidars.

David Bowdle, November 4 - December 1, 1989: San Francisco, California; Honolulu, Hawaii; Pago Pago, American Samoa; Christchurch, New Zealand; Melbourne, Australia; Tokyo, Japan; Fairbanks, Alaska; San Francisco, California. Participated in the First GLOBE Survey Mission as Mission Science Coordinator for the entire deployment.

Maurice Jarzembski, November 11 - December 8, 1989: Melbourne, Australia; Darwin, Australia; Tokyo, Japan; Fairbanks, Alaska; San Francisco, California. Participated in the First GLOBE Survey Mission as Instrument Scientist for the MSFC CW CO_2 Doppler lidars.

David Bowdle, January 13-17, 1990: Pasadena, California. Presented preliminary results from the First GLOBE Survey Mission at the LAWS Science Team Meeting.

Steve Williams, February 14-16, 1990: NASA Ames Research Center, Mountain View, California. Reviewed plans for the Second GLOBE Survey Mission.

Steve Williams, April 26 - May 5, 1990: NASA Ames Research Center, Mountain View, California. Participated in the Second GLOBE Survey Mission as Mission Science Coordinator for the pre-deployment check-out flights.

David Bowdle, May 10 - June 8, 1990: San Francisco, California; Fairbanks, Alaska; Honolulu, Hawaii; Pago Pago, American Samoa; Papeete, Tahiti; Christchurch, New Zealand; Melbourne, Australia; Darwin, Australia; Tokyo, Japan; Honolulu, Hawaii; and San Francisco, California. Participated in the Second GLOBE Survey Mission as Mission Science Coordinator for the entire deployment.

David Bowdle, July 31 - August 3, 1990: Boulder, Colorado. Presented preliminary results of the Second GLOBE Survey Mission at the LAWS Science Team meeting.

David Bowdle, December 1-8, 1990: San Francisco, California. Presented invited paper in the GLOBE Special Session of the Fall Meeting of the American Geophysical Union.

Dean Cutten, January 15-18, 1991, and **David Bowdle**, January 16-18, 1991: New Orleans, Louisiana. Presented papers at the Annual Meeting of the American Meteorological Society.

David Bowdle and Laurie Collins, February 3-6, 1991: Clearwater, Florida. Participated in the LAWS Science Team Meeting.

David Bowdle, March 4-5, 1991: NASA Headquarters, Washington, D. C. Presented a four-year aerosol analysis and modeling proposal to Dr John Theon and Dr. Ramesh Kakar.

David Bowdle, Dean Cutten, and Laurie Collins, April 22-25, 1991: Guntersville, Alabama. Participated in the Ninth Meeting of the GLOBE Scientific Working Group.

David Bowdle, July 6-12, 1991: Snowmass, Colorado. Presented GLOBE results in the Optical Society of America Topical Meeting on Coherent Laser Radar: Technology and Applications.

David Bowdle, Dean Cutten, and Laurie Collins, July 13-18, 1991: Snowmass, Colorado. Participated in the LAWS Science Team Meeting.

David Bowdle, November 12-14, 1991: Hampton, Virginia. Visited Geoffrey Kent at NASA Langley Research Center; presented GLOBE results during a visit by the MSFC LAWS project team.

David Bowdle, November 14-15, 1991: NASA Goddard Space Flight Center, Greenbelt, Maryland. Visited Sury Chudamani to review Goddard lidar data.

David Bowdle, November 18-20, 1991: NASA Jet Propulsion Laboratory, Pasadena, California. Visited Bob Menzies to review JPL lidar data.

David Bowdle, November 20-22, 1991: NASA Ames Research Center, Mountain View, California. Visited Rudy Pueschel, Guy Ferry, and Bob Chatfield (Ames), Tony Clarke (University of Hawaii), and Dave Kutchin (Scripps Institution of Oceanography) to discuss GLOBE data processing and interpretation.

David Bowdle, November 22, 1991: Naval Postgraduate School, Monterrey, California. Visited Phil Durkee to discuss GLOBE results.

David Bowdle, November 25-26, 1991: University of Washington, Seattle, Washington. Visited Bob Brown, Peter Hobbs, Dean Hegg, and Robert Charlson to discuss GLOBE results.

David Bowdle, February 6-7, 1992: NASA Headquarters, Washington, D.C. Presented an invited briefing on GLOBE results to Dr. Shelby Tilford.

Dean Cutten, March 5, 1992: University of Hawaii, Honolulu, Hawaii. Visited Dr. Antony Clarke to discuss GLOBE results.

Dean Cutten, March 19, 1992: Division of Atmospheric Research, Commonwealth Scientific and Industrial Research Organization, Aspendale, Melbourne, Australia. Visited Dr. Martin Platt and Stuart Young to discuss lidar research.

David Bowdle, April 6-8, 1992: NASA Ames Research Center, Mountain View, California. Participated in the Tenth Meeting of the GLOBE Scientific Working Group.

David Bowdle, May 12-15, 1992: Montreal, Canada. Attended the Spring Meeting of the American Geophysical Union to review international lidar research.

David Bowdle, May 18, 1992: NASA Headquarters, Washington, D.C. Presented GLOBE results at NASA's 2.1 μm Technology Review

David Bowdle, June 15-19, 1992: Jouy en Josas, France. Presented GLOBE results at the International Symposium on Active Sensors and Non-Synchronous Missions Dedicated to GEWEX, by invitation of NASA Headquarters.

David Bowdle, July 19-24, 1992: Massachusetts Institute of Technology, Cambridge, Massachusetts. Presented GLOBE results at the International Laser Radar Conference.

David Bowdle, July 27, 1992: Air Force Philips Laboratory, Hanscomb, Massachusetts. Visited Dr. Steven Alejandro and Dr. Donald Bedo to discuss GLOBE data policies.

David Bowdle, Dean Cutten, Laurie Collins, and Cindy Taylor, July 28-30, 1992: North Falmouth, Massachusetts. Participated in the LAWS Science Team Meeting.

Dean Cutten, July 31, 1992: Air Force Philips Laboratory, Hanscomb, Massachusetts. Visited Dr. Steven Alejandro to discuss GLOBE results, and Dr. Bill Snow to discuss new data visualization methods for aerosol and cloud imagery from satellite-based sensors.

Meeting Activity Planning and Support

Prepared by: Laurie Collins

Planning, logistics, administrative support during the meeting and proceedings preparation were undertaken for the following meetings. Facilitation of attendance for the Science Team was provided for workshop participants as needed and travel support was provided as necessary to the Science Team when attending other meetings as a designated member of the LAWS Science Team.

Meeting Activity:

February 1989 - New Orleans, LA - Geostationary Platform Science Steering Committee
March 1989 - MSFC, AL - ESGP Phase A Meeting
May 1989 - Huntsville, AL - GLOBE Science Working Group Meeting
May 1989 - Washington, DC - Geostationary Platform Meeting
July 1989 - Huntsville, AL - LAWS Science Team Meeting
October 1989 - MSFC, AL - ESGP Phase A
January 1990 - Pasadena, CA - LAWS Science Team Meeting
August 1990 - Boulder, CO - LAWS Science Team Meeting
February 1991 - Clearwater, FL - LAWS Science Team Meeting
July 1991 - Snowmass-Aspen, CO - LAWS Science Team Meeting
December 1991 - Toulousse, FRANCE - LAWS Science Team Meeting
December 1991 - Huntsville, AL - LAWS Science Team Meeting
December 1991 - Guerneville, CA - LIS Science Working Group Meeting
July 1992 - Falmouth, MA - LAWS Science Team Meeting

A Regional Scale Pre-Convective Simulation Incorporating A Satellite-Derived Data Assimilation

By

J. Aaron Song, Richard T. McNider and Dan Casey

1. Introduction

Supported by NASA Contract No. NAS8-37585 we have been making initial computations to determine whether high resolution boundary layer modeling in conjunction with satellite derived moisture fields can explain observed meso-beta convective patterns. Mesoscale numerical modeling experiments have been performed on a selected pre-convective environment in which synoptic-scale dynamic forcing is small, while localized convective developments are observed under a favorable condition. The favorable condition seems to be best realized when upward velocities in a vertical motion field generated by the local terrain effect *overlaps* with higher moisture in a satellite-observed lower-tropospheric moisture field. In this report, we first summarize the numerical experiments that have been performed in which diagnostic analysis shows observed storm developed over the locations which are predictable using the GOES satellite data and a mesoscale boundary layer model with high resolution resolving the complex terrain effects. Then, we introduce a newly-derived technique which is designed to prognostically incorporate the satellite hourly surface observation into a mesoscale boundary layer model such that the satellite information is assimilated in a dynamically consistent manner.

2. Diagnostic Mesoscale-Satellite Coupled Analysis

2.1 A Moist-Thermal Mechanism

One of the essential mechanisms by which cumulus clouds develop over a synoptically-undisturbed quiescent environment with complex terrain is the breaking of the capping inversion through a positive feedback effect involving a local thickening of the mixed layer and the in-cloud latent heat release. Figure 1 shows a schematic illustration of a possible breakthrough of the capping inversion by cumulus development within the boundary layer to which terrain-induced mesoscale lifting contributes. If the local lifting condensation level (LCL) is above the mixed layer, no clouds form, but if the LCL is within the mixed layer, dry thermals in the boundary layer, with turbulent velocities generally on the order of $1 ms^{-1}$, can produce shallow cumuli within the layer between the LCL and the inversion base. The cumuli may not be strong enough to penetrate upward if there is no supportive forcing on a larger scale. In the case when terrain-induced mesoscale lifting exists, as shown in figure 1, the mesoscale upward motion produces *both* a moisture convergence (which lowers the LCL) and a rise of the mixed layer top (therefore thickens the layer of the moist thermals). The thickness of the moist thermals is dynamically important, since, once

thickened, the parcels within the cumuli would have a vertically longer path to strengthen, resulting in a larger latent heating and a possibly stronger overshooting at the cloud top. This results in a thicker mixed layer and, consequently, stronger turbulent velocities. The stronger turbulence then, as supported by the continuous mesoscale lifting, produces stronger dry thermals below the LCL and moist thermals above the LCL, and the above process is repeated. Once this positive feedback is established, it can result in a breakthrough of the inversion and deep cumulus convection may initiate thereafter.

2.2 Mesoscale-Satellite Coupling

Mesoscale modeling experiments have been performed over the selected domain shown in figure 2a, in which the complex terrain surrounding the Smoky Mountains is contoured on a 10km-by-10km grid. This domain is chosen from considerations of (1) the GOES VISSR visible and IR (with pixel resolution upto 1kmx1km), as well as the VAS, data must in general be averaged to be used, avoiding the error associated with the solar zenith angle (Gautier et al.,1980); (2) covering enough mountainous area in order to investigate the generation of vertical motions by complex terrain; and (3) use of in-situ observation for model verification from the data of COHMEX (Williams et al.,1987). The mesoscale model produced vertical motion field on the 10km-by-10km grid (the simulation is initiated with the 1400UTC sounding of 19 June,1986, of COHMEX) is shown in figure 2b. Combinning figures 2a and 2b, it can be understood by the good corelation between the terrain and the vertical motions that it is essnetial to use a high-resolution boundary layer model which is able to at least resolve the mesoscale features of the complex terrain in this cae. A 20km-by-20km grid has also been tested (not shown) which does not result in the vertical motions essential to the study purpose of this research.

A split-window retrieval technique (Jedlovec, 1990) was used on the 19 June, 1986, case using the multi-spectral VAS (the window-channel and the lower-tropospheric moisture channel) data which results in a mesoscale distribution of the vertically-integrated precipitable water around 1600UTC over the COHMEX domain. Because different domains are used between this research and that of the retrieval, a Barnes objective analysis is used to analyze the precipitable water data onto the domain of this study, shown in figure 3. As limited by the retrieval data coverage, the precipitable water data over the eastern third of the domain shown in figure 3 (which, unfortunately, includes the Smoky Mountains) must be used with greater care as compared with the rest of the domain. Nevertheless, a moist-tongue can be identified from the precipitable water data which extends southwestwardly from the southeast Kentucky, across Tennessee to northern Alabama, with a local moisture peak around the central Tennessee.

A diagnostic analysis was made which illustrates the mesoscale distribution of the thickness of moist thermals as produced using the model PBL top height and the LCL obtained from a moisture enhencement scheme. The moisture enhencement scheme is designed to incorporate the satellite moisture pattern into mesoscale modeling in which the moisture field is otherwise a completely passive model variable. Currently, the scheme uses a *base* surface moisture field (a constant value), and multiply to it

grid-by-grid a *ratio* defined as dividing the grid-point precipitable water by the domain-averaged precipitable water. This results in a more realistic surface moisture distribution over the mesoscale domain, which would not be possible to be generated from using simply an ordinary mesoscale boundary model such as that used in this research (originally developed by Pielke,1974). With this refined surface moisture, the LCL can be calculated, and, by subtracting the LCL from the model PBL height, the moist thermal thickness field is obtained, shown in figure 4. From figure 4, it is seen that over the central Tennessee and over the Smoky Mountains, larger positive values of the moist thermal thickness are found, whereas negative values can be seen surrounding the Smoky Mountains. Figure 5 shows the GOES VISSR visible image of 2000UTC, 19 June, 1986, on the 10km-by-10km grid, whch indicates storm developments, as seen from the much larger brightness values over the cloud tops, in certral Tennessee and over the Smoky Mountains. Qualitatively, this meso-beta scale convective pattern seems to be predictable, or at least explainable, using the aforementioned mesoscale boundary layer model in conjunction with the satellite-derived moisture enhancement scheme.

3. On-Going Research

Incorporation of satellite information in regional scale atmospheric modeling may be denoted as a numerical modeling with one type of Four-Dimensional Data Assimilation (FDDA). Generally, on the global scale the FDDA has been carried out during the past two decades with the use of the balanced-equation constraint through the geostrophic adjustment process. On the mesoscales, or scales smaller than the Rossby radius of deformation, however, the FDDA seems currently subject to a certain degree of uncertainty. The problem seems to not just concern that the balanced-equation may not hold on mesoscales, but also that the traditionally linearly-derived radius of deformation may not be itself meaningful (Stauffer et al.,1991). A single-level (surface) data assimilation does not seem to result in improvement on the regional scale simulations (Dr. N. Seaman; personal communication). Even with a deep-layer information, for instance using the VAS data, Hayden and Schmit (1991) indicated that without a proper dynamic constraint the current satellite-derived FDDA does not seem to be able to *consistently* improve on the mesoscale numerical modeling.

An experimental thermodynamic/dynamic constraint linking the GOES hourly data and mesoscale boundary layer modeling is currently under development in this research. Figure 6 shows schematically the computational steps of assimilating satellite skin temperature information (in terms of hourly changing rates) into the mesoscale PBL modeling which determines the surface temperature and moisture as well as the sensible and latent heat fluxes across the air-ground interface. In McNider et al.(1993) this data assimilation approach is introduced and discussed using the one-dimensional data from FIFE (First ISLSCP Field Experiment; where ISLSCP: International Satellite Land Surface Climatology Program), while in Song et al.(1993) three-dimensional experiments incorporating this data assimilation will be discussed with real-case simulations using observations from COHMEX and CaPE (Williams et al.,1992).

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Gautier C., G. Diak and S. Masse, 1980: A simple physical model to estimate incident solar radiation at the surface from GOES satellite data. J. Appl. Meteo.,Vol.19,1005-1012.

Jedlovec, G. J., 1990: Precipitable water estimation from high-resolution split window radiance measurements. J. Appl. Meteo.,Vol.29,863-877.

Hayden C. M. and T. J. Schmit, 1991: The anticipated sounding capabilities of GOES-I and beyond. Bullet. Amer. Meteo. Soc., December 1991.

McNider R. T., J.-L. Song, W. Crosson and P. Wetzel, 1993: Toward the development of a thermodynamic/dynamic assimilation of satellite information in surface energy budgets. (to be submitted to Intl. J. Remote Sensing)

Pielke, R. A., 1974: A three-dimensional numerical model of the sea breeze over south Florida. Mon. Wea. Rev.,102,115-139.

Stauffer D. R., N. L. Seaman and F. S. Binkowski, 1991: Use of Four-Dimensional Data Assimilation in a limited area mesoscale model Part II: effects od data assimilation within the planetary boundaru layer. Mon. Wea. Rev.,119,734-754.

Song J-L, R. T. McNider, P. Wetzel and D. Casey, 1993: A regional scale pre-convective simulation incorporating a satellite-derived data assimilation. (to be submitted to J. Appl. Meteo.)

Williams S. F., H. M. Goodman, K. R. Kevin and J. E. Arnold, 1987: Space/COHMEX Data Inventory Document. NASA Tech. Memo. 4006, NASA.

Williams S. F., K. Caesar and K. Southwick, 1992: The Convection and Precipitation Electrification (CaPE) Operations Summary and Data Inventory. NCAR.

FIGURE CAPTIONS

Figure 1: A schematic illustration showing a more effective breakthrough of a capping inversion by cumuli development between the LCL and the PBL top under a mesoscale terrain-induced lifting, in contrast to a less-likely breakthrough in which no mesoscale lifting contributes.

Figure 2: (a) Topography heights (m) plotted on a 4.5km-by-4.5km grid over the study domain, with contouring interval of 200m; and (b) Model produced vertical motions (cm/s), averaged over the layer of 1-2km above the surface, on a 10km-by-10km grid with solid/dashed lines indicating upward/downward velocities and a contouring interval of 10 cm/s.

Figure 3: Precipitable water (cm) distribution on a 10km-by-10km grid over the study domain at 1600UTC, 19 June, 1986, as obtained from the use of a split-window retrieval technique (developed by Jedlovec,1990).

Figure 4: Mesoscale distribution of the thickness (m) of Moist Thermals (defined as the layer thickness between LCL and PBL top) around 1800UTC, 19 June,1986, on a 10km-by-10km grid, obtained from a mesoscale-satellite coupled diagnostic analysis (see text for details).

Figure 5: The GOES VISSR visible image in brightness (0-255), as plotted on a 10km-by-10km grid, on 2000UTC, 19 June,1986, over the study domain. Relatively much higher brightness (around 200) show the cloud tops of deep convection, while lower brightness (80-100) generally indicate surface under clear-sky.

Figure 6: A schematic illustration showing the computational steps of an experimental data assimilation technique developed in this research, which shows the incorporation of satellite skin temperature hourly changing rates into a prognostic surface energy balance equation in such a way that the assimilated satellite information is dynamically and thermodynamically consistent with that of the mesoscale model (details are discussed in McNider et al.,1993 and in Song et al.,1993).

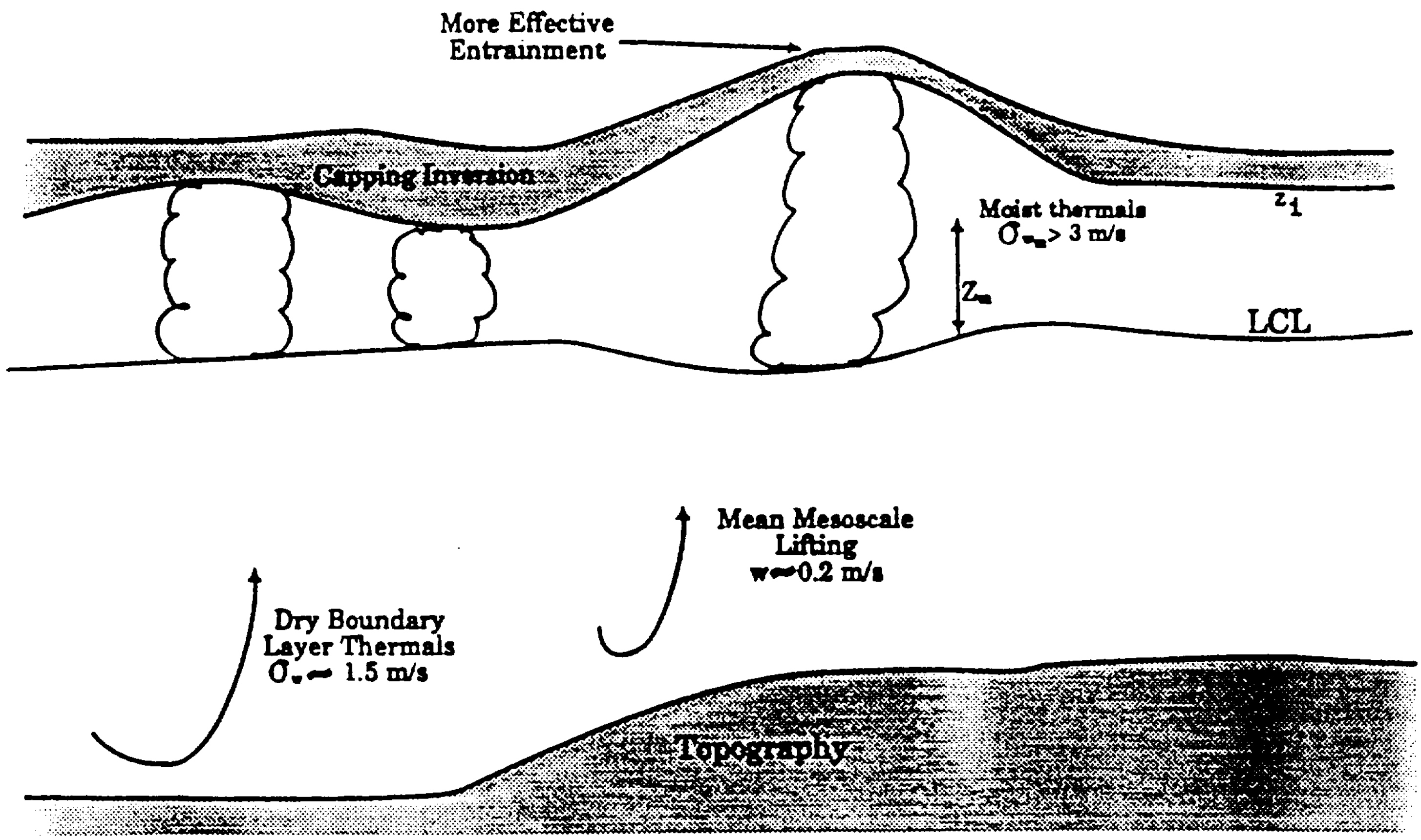
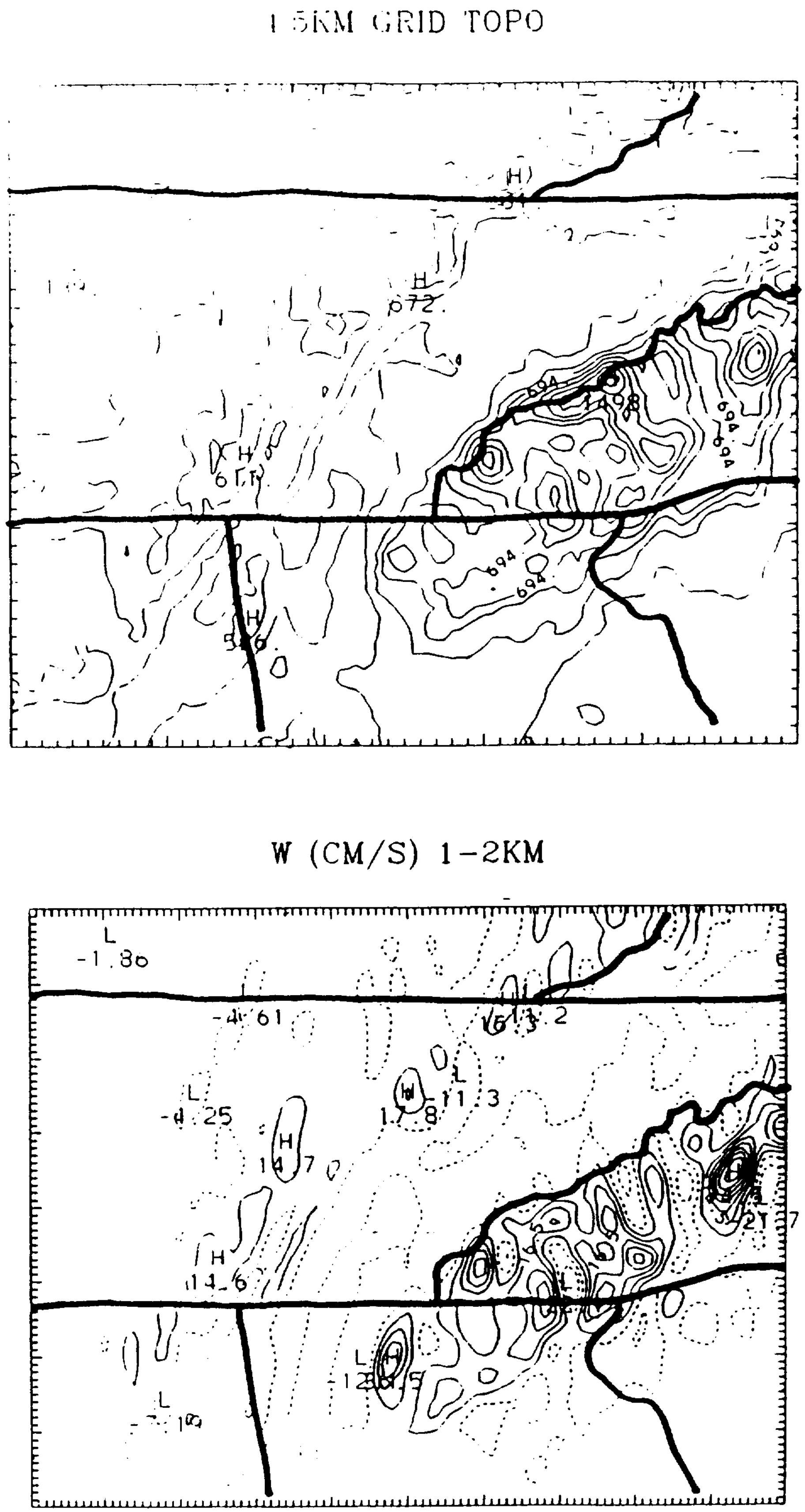

More Effective Entrainment
Capping Inversion
Moist thermals
$\sigma_{w_m} > 3$ m/s
z_i
Z_m
LCL
Mean Mesoscale Lifting
$w \sim 0.2$ m/s
Dry Boundary Layer Thermals
$\sigma_w \sim 1.5$ m/s
Topography

Figure 1



(a)

(b)

Figure 2

Fig 2

PRCWTR (CM) 16Z

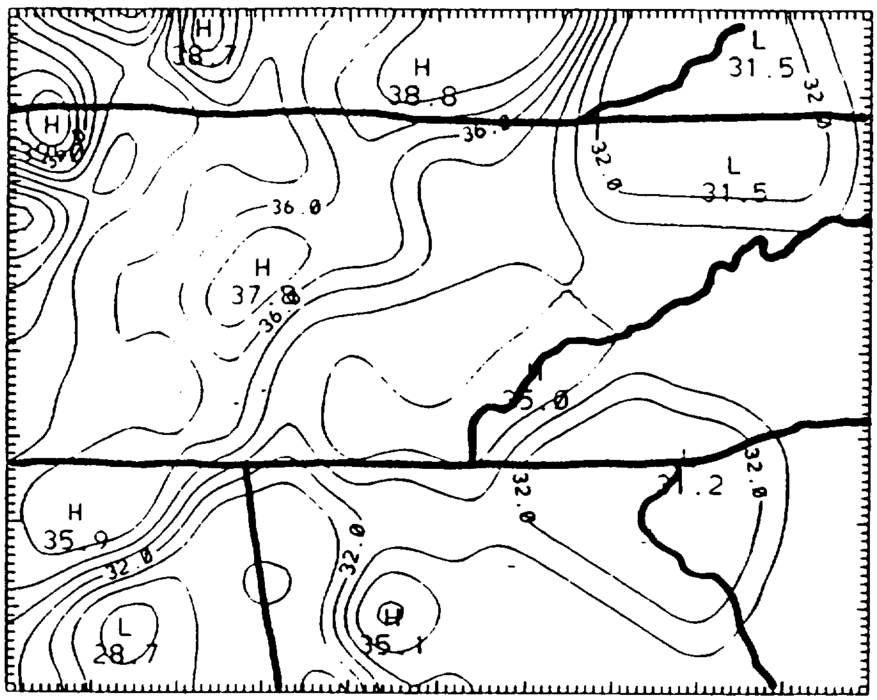


Figure 3

Fig 3

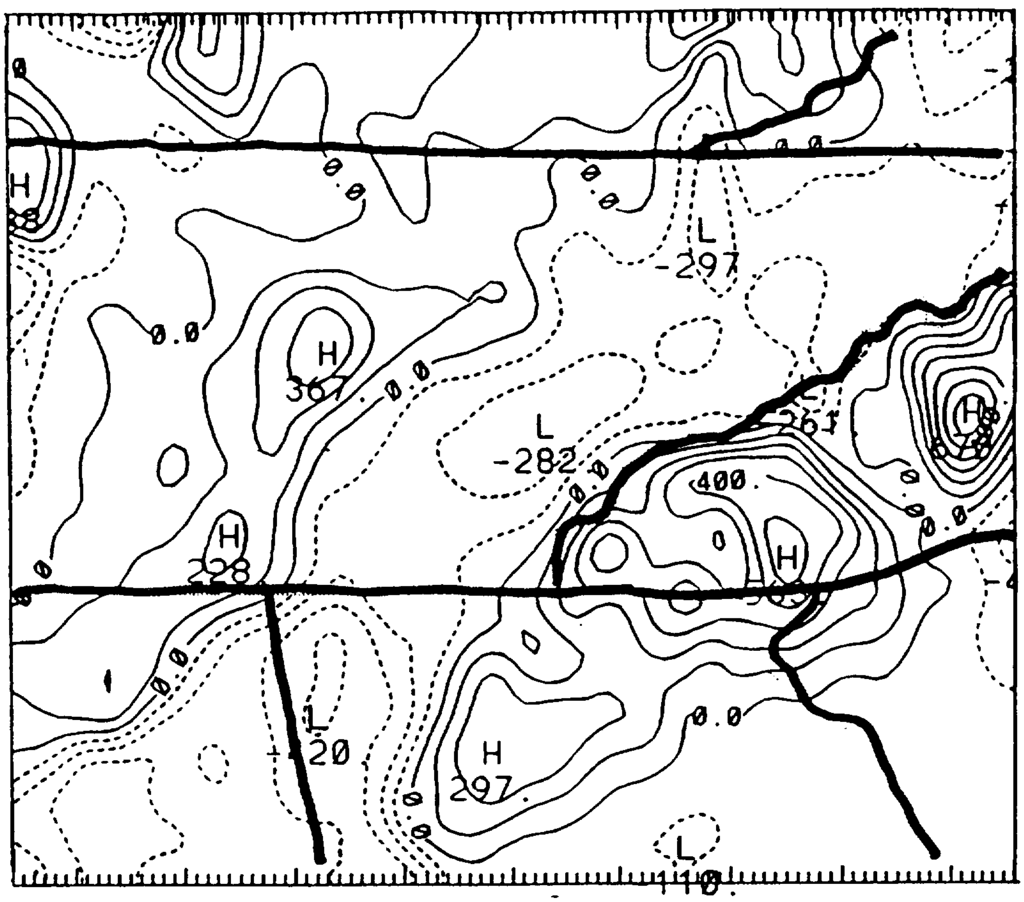


Figure 4

Fig 1

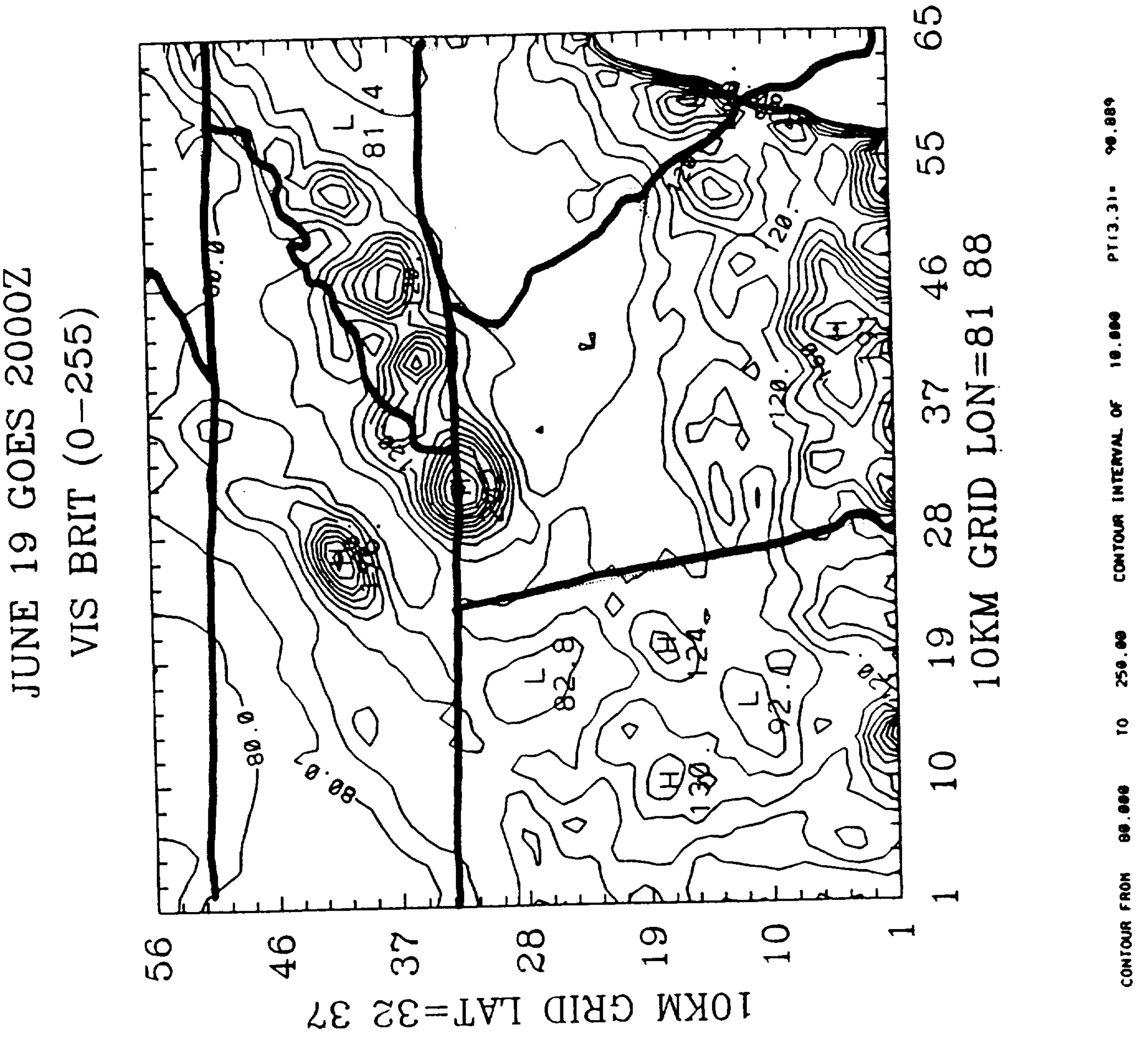


Figure 5

Fig 5

CALIBRATION FLOWCHART

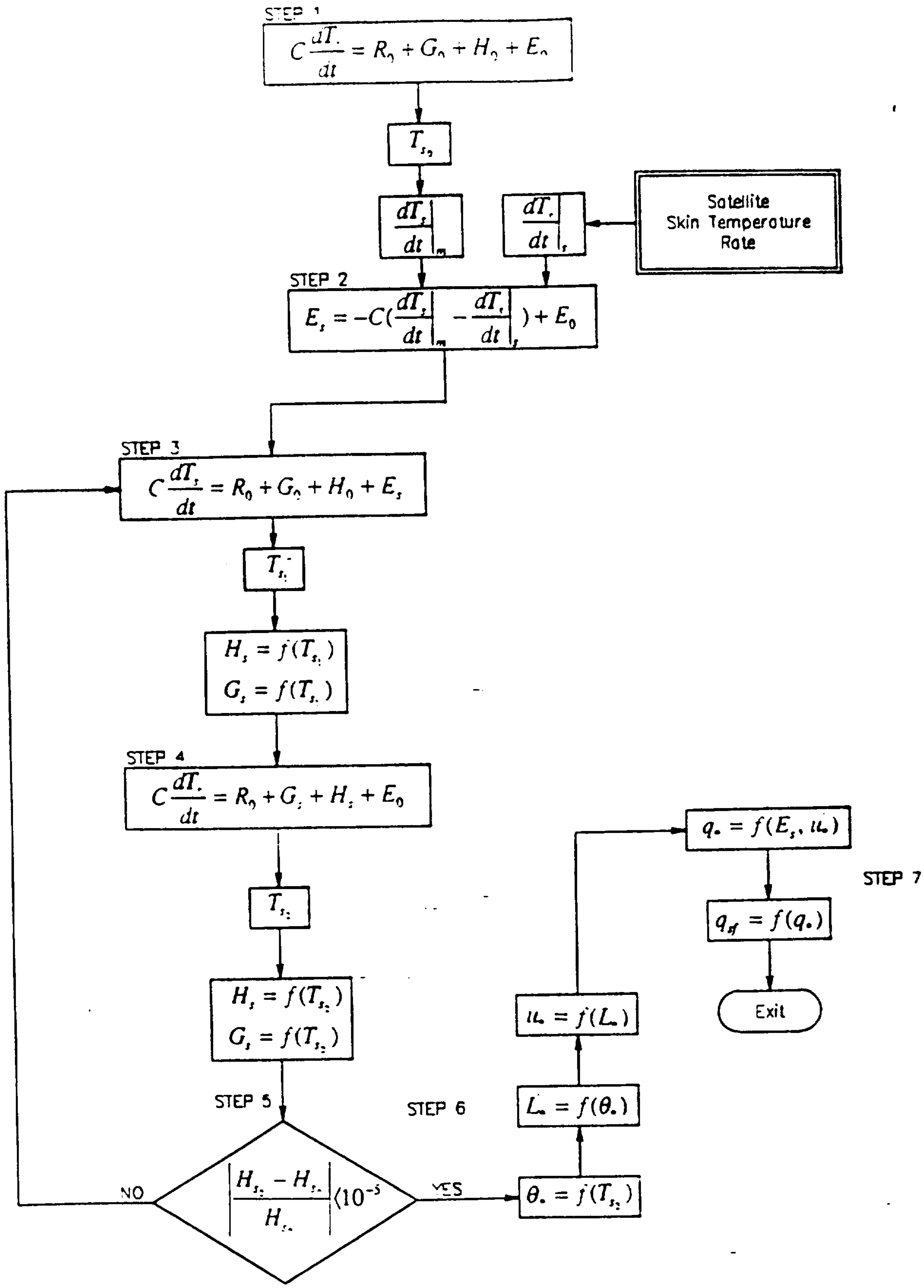


Figure 6

Fig 6

Prepared by

Douglas Mach

I. Task 1

High Altitude Aircraft Instrument Package

My part of task 1 was to help with the integration of the presently available instruments onto the new platform. I also participated in the selection of new instruments and experiments to be built and integrated into the new platform.

II. Task 2

Optical Pulse Analysis

This task dealt with the analysis of presently available optical pulse data collected on the many U-2 storm overflights made by the lightning group at NASA/MSFC. The data set consisted of a huge number of pulses taken from many storms over several years. Because of the immense number of pulses in the data set, it was ideal for performing statistical pulse analysis. My major effort in this sub-task was concentrated on perfecting an automatic program to find and categorize the optical pulse data. I was able to correct and debug a program to do automatic analysis of the pulse data and I have tested the program on smaller subsets of the data base. My task in the next year was also to have the program do the analysis on the complete data set and to determine the relevant pulse characteristics. These included pulse rise times, pulse duration, pulse shape, pulse fall time, and optical and electric field arrival time delays. Once the statistics were determined, I compared my results to those of others to determine any differences.

Cloud Light Scattering Model

One of the questions raised in previous work in the detection of optical pulses from clouds is that the optical signals seem to lag the electric field pulses. In addition, the optical pulses detected from above the cloud have different characteristics than the pulses from lightning detected below the cloud. One possible explanation for this is that the scattering and absorption of light by cloud particles delays and distorts the optical pulse as it passes through the cloud. I tested this theory by modeling the interaction of the cloud particles and the photons by using a simple Monte Carlo cloud model to simulate the interaction of cloud particles with photons. This program yielded some interesting results. I produced a large data base of pulse delay, and angular, and spectral dependence for the spectral bands that are detected by the NASA/MSFC optical instruments. The results of the cloud model studies were then used as calibrations for theoretical studies of the optical scattering process.